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Design Approach of Double Pass Electrostatic Precipitator with Ceramic Foam Filter to Reduce Diesel Engine Emissions

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***Abstract*: Global warming and climate change are two main concerns to the whole planet causing abnormal weather patterns leading to climate extremes such as heat waves, rise in sea levels and loss of natural habitat. Many countries are united to fight against drastic climate change by setting up benchmark to reduce the emission of greenhouse gases. Exhaust gases from various industries and vehicles leads to various adverse effects on the environment leading to global warming as well as climate change. The present paper is an attempt to design a lab scale prototype of double stage electrostatic precipitator (ESP) with ceramic foam filter in order to reduce the pollutants level in diesel engine emissions. Constant high voltage is applied to both the stages of ESP in order to remove the suspended particles from exhaust by collecting them on charged plates by minimally impeding the gas flow and then it is made to flow through the ceramic foam filter in order to increase the collection efficiency of whole setup in order to trap the maximum possible pollutant emissions from the diesel engine exhaust.**

***Keywords*: Electrostatic precipitator, climate change ceramic foam filter, global warming, High voltage.**

1. Introduction

Climate change is the most serious warning to the planet which is evident by the rise of global temperature by 0.8 degree Celsius since 1880 causing sea level to rise 3.3 millimeters per year leading to dislocation of human communities as well as alteration of eco systems by making few species already extinct and some are in the verge of extinct. Greenhouse gases are one among the major causes of climate change. Climate change is being counted as a global environmental threat caused by people. It is seen as the second most serious issue that the world faces and has brought about results that affect life adversely [1]. Diesel engines are widely used in automobiles, ships, locomotives, electric power generators and other applications because of the great advantages that offer as compared to gasoline engines, including lower CO2 emissions, higher torque output and lower fuel consumption [2].

Figure 1 illustrates the structure of green house gases where water vapor accounts 50% in atmosphere which is the most abundant green house gas that increases the earth's temperature contributing to greenhouse effect then comes carbon-di-oxide accounting 20% which is released through natural process such as respiration, deforestation, volcanic eruptions. Human activities takes complete responsibility in sudden rise of carbon-di-oxide which is increased by more than third since industrial revolution began and according to the measurement of NASA as of 2019 it has reached 410.94 ppm in the atmosphere making it worse for the climate change. Methane, Nitrous oxide, Chlorofluorocarbons (CFCs) are the other three greenhouse gases responsible for climate change which are released to the atmosphere through human activities such as agriculture, waste deposition, fossil fuel combustion and biomass burning [5].

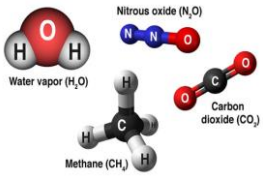

Fig. 1. Greenhouse gases

The particles emitted from diesel engine exhaust are low resistive in nature and extremely small in the range of 70–120nm. These particles penetrate into the alveoli of the lungs and are extremely harmful to human health [3]. The demand for more efficient automobiles has increased due to the sharp increase in oil prices. At the same time, strong economic growth in several countries has caused serious air pollution due to exhaust from vehicles [6].

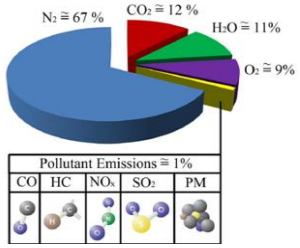

Fig. 2. Diesel exhaust emission composition

Emissions form diesel engine are more harmful compared to petrol engines and diesel exhaust from the vehicles & industries is the main origin of atmospheric soot and fine dust particles causing is the various health hazards and it should be treated with proper technology before emitting to atmosphere [4] and figure 2 depicts the percentage of various pollutants in diesel exhaust emission.

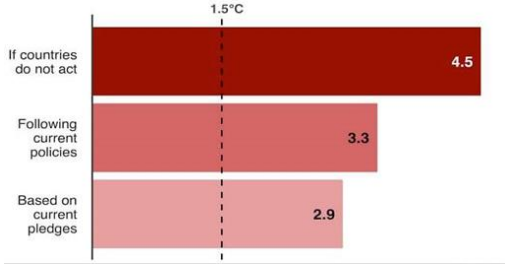

Fig. 3. Average temperature warming projected till 2100

According to some recent analysis & reports from various organizations as shown in figure 3, Climate change at this rate may end human civilizations at some parts of the world due to increase in temperatures by 2050.The only way to avoid such risks is to build out zero emission systems for industries which may help in restoration of safe climate. According to NASA earth's temperature is increased by 0.8 degree Celsius since 1880 and if this rate of global warming is continued then earth's temperature trajectory will result in rise of approximately 3 degree Celsius by the year 2050 causing oceans to hold much heat leading to melting ice sheets by raising sea levels leading to damage of eco systems.

Electrostatic precipitator (ESP) is one among the technologies for removing particles, and it has been used satisfactorily for the cleaning of flue gas from large-capacity factories, combustion furnaces, and thermal power plants. Here an approach is made to design double pass ESP with ceramic foam filter to reduce the pollutants level from the diesel engine emission.

2. Proposed Method

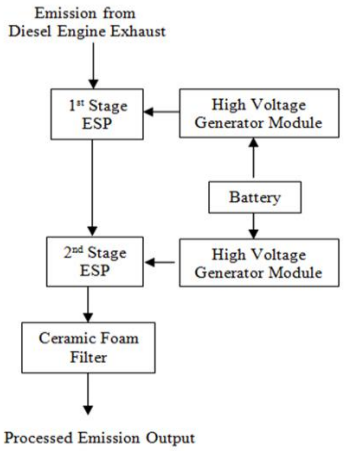

Fig .4. Block Diagram of Double Pass ESP with Ceramic Filter

Figure 4 summarizes the block diagram of double pass ESP with ceramic foam filter, The double pass ESP passage is built placing ESP's back to back continuously by supplying high DC voltage from a battery using high voltage generator module where 6V is converted to nearly 400KV.Ceramic foam filter is placed at the end of the passage to trap pollutant levels further from the emission that is left out from the double stage ESP filtration unit .The motive of this design approach is to reduce the pollutant level from the diesel engine emission to certain extent for avoiding the various environmental problems caused to this planet. When the diesel emission is fed in to the double stage ESP, gas sensor measures the inflow as well as outflow gas at the end in parts per million (ppm) with percentage of CO in the gas and that's how results are analyzed. In this model ceramic foam filter is used to increase the efficiency along with double stage ESP where passage of ESP is made up with PVC plastic pipe of length 40cm, diameter 10.5cm and distance maintained between the two ESP's is 20cm where stainless steel alloy electrodes are used with thickness 2mm.

3. Hardware components

A. Electrodes

Fig. 5. Stainless steel alloy collection electrodes

The quality of ESP is mainly dependent on the type of collection electrodes which alone determines the collection efficiency of pollutants from emission. Collection electrodes are charged by supplying 400KV High Voltage DC for inducing proper electrostatic charge to collect the pollutant particles from the gas passage of double stage ESP. Stainless steel alloy electrodes with 2 mm thickness placing them 150mm apart are used in this model as shown in figure 5 over carbon steel electrodes as they can easily undergo corrosion.

B. Battery

Fig. 6. Battery

Lead acid rechargeable battery of 6v and 4.5 ampere hour is used as the primary power source for this model as shown in figure 6 and they have very low energy to weight ratio as well as energy to volume ratio along with the capability to supply high surge currents. These batteries are cost effective and economical which can be recycled easily making it ecofriendly.

C. High voltage Generator module

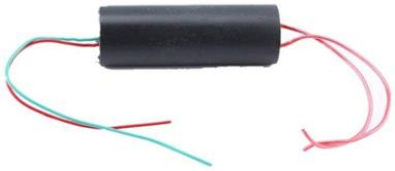

Fig. 7. High voltage generator module

The ESP needs High DC voltage to charge its electrodes in order to induce the charge on scattered dust particles from the gas flow in order to trap them. Hence in this model 6v from a battery is stepped up to 400KV high DC voltage using high voltage generator model as shown in figure 7. This high voltage model is based on the principle of tesla coil which is made of high voltage pulse output. The input terminal takes dc voltage of range between 3.2v-7.2v stepping up to 400KV high DC voltage which is enough to generate the arc within the range of 100-200 mm with the help of high pressure inverter transformer designed inside the module.

D. Ceramic Foam Filter

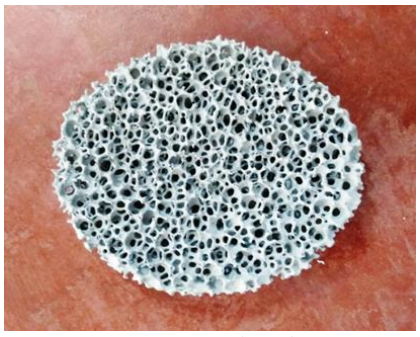

Fig. 8. Ceramic foam filter

Diesel particulate filter (DPF) is a flow-through device which absorbs bigger exhaust gas particles by forcing the gas to flow through it. There are many types of DPF's are available in the market which are designed to suit the application that is used. In this model ceramic foam filter as shown in figure 8 is used to retain the amount of particles present in the gas flow because of its properties such as high temperature resistance with large surface area resulting in high porosity as well as its very economical compared to other DPF's with strong chemical corrosion. The filter that is used in this model has diameter of 10 cm placed at end of the passage of double pass ESP.

E. Low Voltage Brushless Fan

Fig. 9. Low voltage brushless fan

The low voltage brushless fan as shown in figure 9 is used at the end of the passage of the model to pressurize the gas flow from input through double pass ESP and ceramic foam filter. It is powered by the same battery directly which powers the ESP using 12V power supply. The fan has 2 pins with brushless motor application with dimensions of length 50mm, breadth 50mm and height 15mm.

4. Lab scale model preview

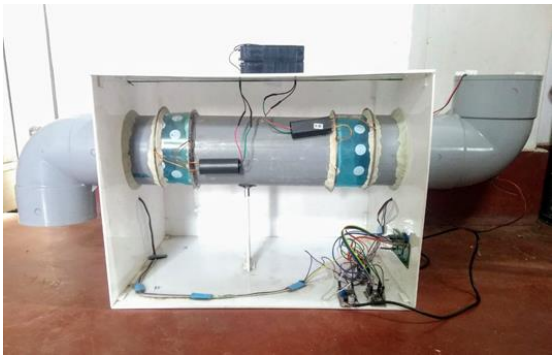

Fig. 10. Lab scale model

Fig. 11. Ceramic foam filter

5. Results and Discussions

Table 1 shows the measured concentration of diesel emission inflow which is primarily measured as well as outflow measurement is done for four cases i.e. single ESP, single ESP with filter, double ESP and double ESP with filter respectively. These values are taken from the average of 10 measurement

values which are considered as gas flow varies continuously with time.

Table 1
Gas Inflow and Outflow Measurement

Parameters	CO (ppm)	Overall Emission (ppm)
Inflow	5486	1694
Outflow (Without any Filtration)	2286	329
Outflow (Single ESP)	1600	231
Outflow (Single ESP with Filter)	1486	214
Outflow (Double ESP)	1280	185
Outflow (Double ESP with filter)	1165	168

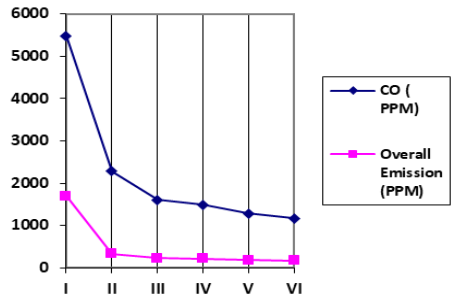

Fig. 12. CO and Overall emission

In the above bar graph, Blue line illustrates the CO reduction in ppm after treatment. whereas pink line depicts the reduction of overall emission in ppm.

6. Conclusion

This double stage ESP with ceramic foam filter has been comparatively more effective. With the use of double stage ESP and ceramic foam filter it is possible to reduce the pollutant level concentration as well as CO emission from a diesel engine approximately up to 40% which is 10% more than using single stage ESP with filter or double stage ESP alone. As climate change is being the main concern to the planet, every tiny measure taken towards the prevention of air pollution will be contributed so much to the safety of the planet directly or indirectly as carbon capture is the main concern leading to climate change.

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